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## Evolution of the structure of ferritic steels subjected to torsion

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### Abstract

The power plants operate in service under conditions of high temperature and applied stress states. Under these conditions the components are subjected to degradation mechanisms that can lead to damage them. The components used in service are usually manufactured with ferritic steels, resistant to high temperature and with different structures of precipitates which change over time and alter the resistance of the material. It is then possible to observe variations in the chemical composition of the matrix, decomposition of areas of pearlite / bainite, and carbide precipitation and transformations by changes in the morphology.

The objective of this work is to study the microstructural changes that occur in 2.25Cr 1Mo and 1.25Cr 1Mo 0.25V steels, subjected to creep at stresses between 131 and 205 MPa and temperatures between 843 and 923K. Simultaneously, thermal treatments in the same ranges of temperatures are performed on the abovementioned steel, to differentiate structural changes due to temperature than those caused by stress.

The microstructure of the material under stress states and high temperature shows deformed grains with smaller size in comparison with the as received material and increased precipitation of carbides.

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**Keywords** : Ferritic steels, Torsion, Mechanical properties

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**Nomenclature**

$\dot{\epsilon}$	creep strain rate (s <sup>-1</sup> )
$\sigma$	uniaxial stress (MPa)
A	constant depending of the structure
Q	activation energy (J)
R	universal gas constant (J/K)
T	absolute temperature (K)
n	stress exponent

**1. Introduction**

The mechanical components operating under critical conditions of temperature and stress suffer different degradation mechanisms that can lead to damage of the material.

One of them is the creep, where the material deforms plastically as time goes on by changing its structures. It is important, for the industrial design, to know the creep resistance of the material because avoids economic losses caused by the failure of components [Viswanathan et al., 1989].

In the power generation plants, the components are subjected to creep as they work at temperatures around 873 K and under constant stress states. Particularly, for the manufacture of boiler superheaters low alloy ferritic steels are used which have a low coefficient of expansion and high thermal conductivity. In order to ensure that the operation of the equipment is correct for the estimated service life it is necessary that the material keeps a stable microstructure along that time. This can be achieved when the operating time is approximately of 100 hours, but it is difficult when the service life exceeds 200.000 hours, typical value in the power plants [Bhadeshia et al., 2001].

The creep strength-enhanced ferritic steels (CSEF) have a stable microstructure with fine carbides that impedes the movement of dislocations. However it is inevitable that over long periods of service or very critical conditions, microstructural changes occur that are responsible for the loss of resistance of the material. The modifications of the structure include: transformation of carbides, precipitation and decomposition of areas of pearlite / bainite, changes in the morphology of the carbides and variation in the chemical composition of the matrix. The characteristics of these changes depend essentially on the chemical composition of steel, its previous history and working conditions (temperature and stress).

Thompson and Badeshia, indicate that the prevalence of some of these changes depend on the microstructure of the material and Viswanathan, 1989 analyzed the influence of the alloying element in the resistance to creep of ferritic steels. These authors find that the Cr, Mo, W, V, Ti, Nb, Zr, Mn and P increase the metal resistance while C, Ni, Cu and S favours the decohesion phenomenon.

In this paper, the creep behaviour of the 2.25Cr 1Mo and 1.25Cr 1Mo 0.25V ferritic steels subjected to torsion creep tests is analyzed and the study of the influence of alloying elements on the creep resistance and on the characteristic parameters is performed. Parameters such as the stress exponent and the activation energy are related with the strain rate, load and temperature. The torsion creep tests have the possibility to work at a constant stress without the necessity of complex equipment.

Thermal treatments were performed in the same temperature range to differentiate structural changes due to temperature from those caused by stress.

## 2. Experimental method

Creep test were carried out in 2.25Cr 1Mo and 1.25Cr 1Mo 0.25V cylinder specimens obtained from seamless pipes used in superheaters of a power generation plant. The chemical compositions of the steels are given in Table 1.

Table 1. Chemical composition of steels (weight%).

Steel	C	Cr	Mo	V	Ni	Mn	Si	Cu	Others	Fe
2.25Cr 1Mo	0.16	2.23	0.96	-	0.07	0.40	0.03	0.09	S, Sn <0.010	Balance
1.25Cr 1Mo 0.25V	0.14	1.10	0.95	0.24	0.40	0.69	0.35	-	P, S <0.03	Balance

The geometry of the cylinder specimens is shown in Figure 1.

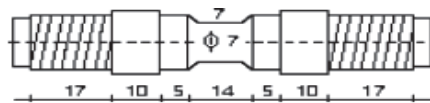


Fig. 1: Schematic drawing of the steel specimen used for creep test (mm)

The microstructure of the steels in their as received condition is shown in Fig. 2, where it is possible to see that the structure corresponding to the 1.25Cr 1Mo 0.25V steel is mainly bainitic, while that of 2.25Cr 1Mo steel is essentially ferrite / bainite.

In torsion creep tests, the strain is calculated taking into account the angular movement of a determined point of the probe, maintaining the other end fixed. The torsional moment is obtained applying a constant torque and this is the unique cause of the axis rotation [Bailey et al., 2001].

The creep test is performed using a torsion machine with an electric furnace. The hot end of a chromel–alumel thermocouple is located in contact with the surface of the calibrated zone of the specimen.

The creep test is carried out at the stress ( $\sigma$ ) of 168MPa, and at temperatures of 843, 873 and 893K, in probes of 2.25Cr 1Mo and 1.25Cr 1Mo 0.25V steels.

The equivalent strain rate is determined using the empirical equation (which is related with the stress and temperature) expressed as: [Evans et al., 1985].

$$\dot{\epsilon} = A \sigma^n e^{-Q/RT} \quad (1)$$

The study of the microstructure allows interpreting the kinetic transformations in the precipitated phases, the nucleation and evolution of microcavities responsible for the damage.

The microstructure was analyzed in order to study the changes in the precipitated phases and the nucleation and evolution of microcavities responsible for the damage.

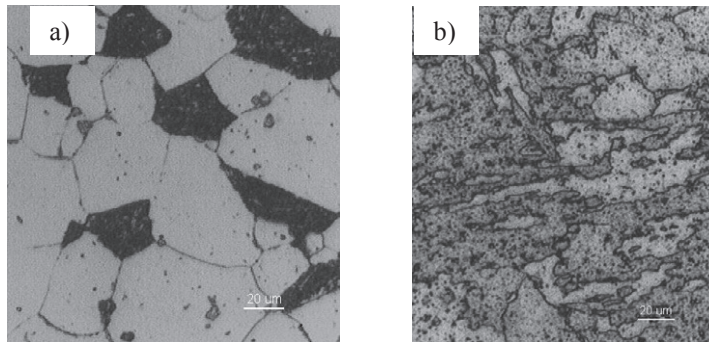


Fig. 2. Optical micrographs in the as received condition state. Etching reagent: Nital 2 %. (a) 2.25Cr 1Mo, (b) 1.25 Cr 1Mo 0.25 V

### 3. Results and discussion

Creep tests were performed at different stresses and temperatures to evaluate the behavior of the material when exposed to these conditions. Figure 3 shows specific deformation as a function of time under a constant temperature of 873K at applied stresses between 131 and 205 MPa.

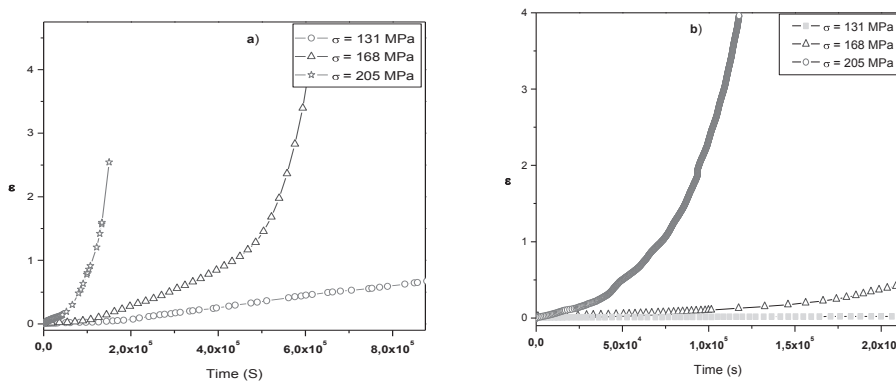


Fig. 3. Creep curves: (a) 2.25Cr 1Mo and (b) 1.25Cr 1Mo 0.25V.

The strain rate for stationary state was calculated. Equation 1 can be rewritten as Eqs. (2) and (3), by using logarithms, obtaining the  $n$  and  $Q$  parameters for constant stress or temperature:

$$\ln \dot{\epsilon} = \ln (A \sigma^n) - \frac{Q}{R T} \quad (2)$$

$$\log \dot{\epsilon} = \log (A e^{-Q/RT}) + n \log \sigma \quad (3)$$

The logarithmic graphic representations of these equations should result in straight lines, so the parameters can be easily obtained from the slopes.

Activation energy  $Q$  can also be calculated from the power law (equation 1). Based on tests performed at different temperatures and under a constant stress, strain rate as a function of the reciprocal of the temperature is plotted in Figure 4. Results were adjusted by a linear regression through a line of slope proportional to  $Q$ .

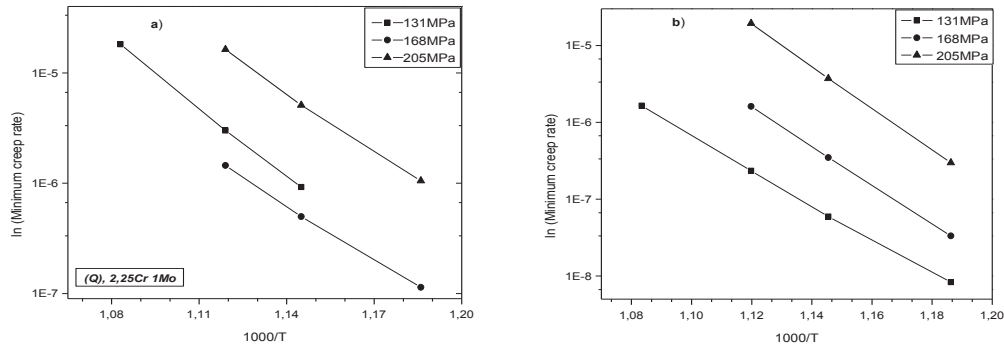


Fig. 4. Logarithmic plot to determine the activation energy ( $Q$ ) for: (a) 2.25Cr 1Mo and (b) 1.25Cr 1Mo 0.25V. The straight line regression for the activation energy is shown.

The values of the activation energies obtained are shown in Table 2.

Table 2: Activation energy (kJ/mol) at different stress

Stress ( $\sigma$ )	2.25Cr 1Mo	1.25Cr 1Mo 0.25V
131MPa	320,8	443,8
168MPa	330,5	493,3
205MPa	341,7	526,2

The activation energy of each steel increase with the increase applied stress. This parameter is higher in the 1.25Cr 1 Mo 0.25V steel. This behavior indicates less resistance to creep.

With a similar procedure, creep strain rate values as a function of the mechanical stresses are represented for constant temperatures of 843, 873 and 893 K, Figure 5. Results were adjusted by a linear regression through a line whose slope allows obtaining the values of the stress exponent ( $n$ ). These values are indicated in Table 3. It is also possible to observe higher values of the stress coefficients in the 1.25Cr 1Mo 0.25V steel.

The values of stress exponents " $n$ ", calculated for both steels indicate that the dominant process in flow is the dislocations movement. The presence of alloying elements as Cr and V would increase the resistance of ferritic steels.

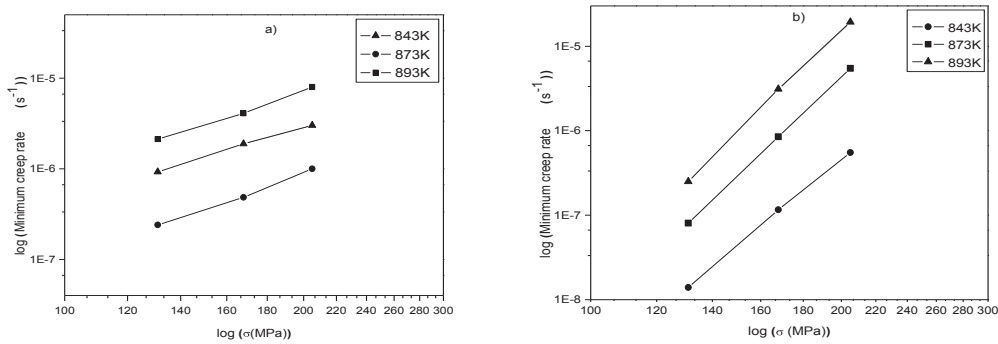


Fig.5. Logarithmic plot to determine the stress exponent (n) for both steels. (a) 2.25Cr 1Mo and (b) 1.25Cr 1Mo 0.25V

Tabla 3: Stress exponent

Temperature	2.25Cr 1Mo	1. 25Cr 1Mo 0.25V
843 K	2.6	6
873 K	3.7	9.4
893 K	4.8	9.89

Figure 6 presents the variation of the microstructure of both materials after having been subjected to creep. It is possible to see a decreased grain size and the deformation of the grains. There is also an increased precipitation of carbides with the consequent decomposition of the colonies of bainite. This effect becomes more noticeable as the test temperature increases.

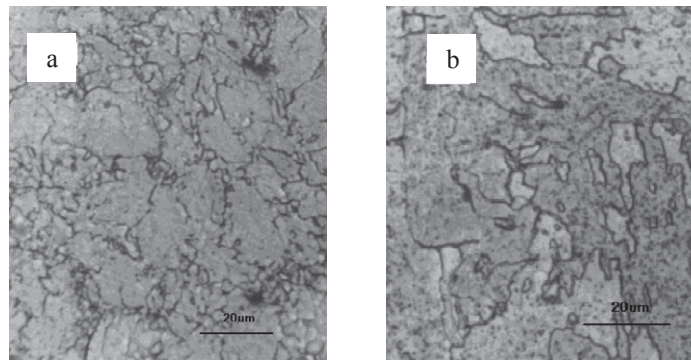


Fig. 6. Micrographs showing the variation of the structures by effect of temperature and stress. Etching reagent: Nital 2%. (a) 2,25Cr 1 Mo, (b) 1,25Cr 1Mo 0,25V

To study the influence of only the temperature on the material annealing heat treatments at the same temperature and during the same time than those of the creep tests were performed and the resulting microstructures were observed Fig. 7.

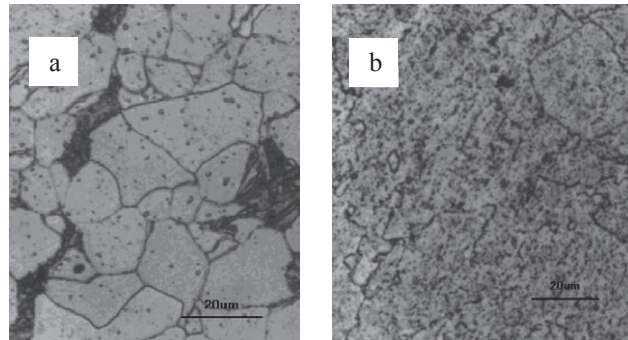


Fig. 7. Micrographs indicating the variation of the structures by effect of temperature. Etching reagent: Nital 2%. (a) 2,25Cr 1 Mo, (b) 1,25Cr 1Mo 0,25V

In the material that was thermally treated it is possible to see that for both structures the precipitation of carbides increases with increasing test temperature. Fig. 8 shows the structure and EDX analysis of carbides for both steels.

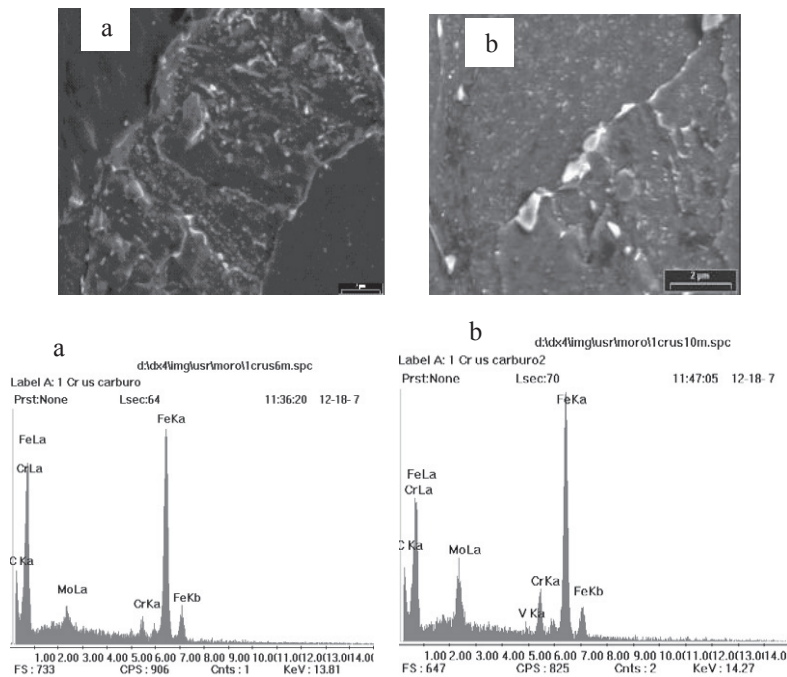


Fig.8. Electron microscopy SEM and spectroscopy EDX of carbides. (a) 2,25Cr 1 Mo, (b) 1,25Cr 1Mo 0,25V



It is observed that in the 2.25Cr 1Mo steel the carbides are mostly of chromium but there are also presences of molybdenum carbides, while the 1.25Cr 1 Mo 0.25V steel exhibits the same types of 2.25Cr 1Mo precipitates with vanadium carbides.

Bhadeshia, 1992 proposes that resistance to creep in the 2.25Cr 1Mo steel is due to a fine precipitation of carbides which varies according to temperature and service time; these initially are carbides  $\text{Fe}_3\text{C}$  and  $\text{M}_2\text{C}$  carbides which then evolve to  $\text{M}_{23}\text{C}_6$ ,  $\text{M}_7\text{C}_3$  and  $\text{M}_6\text{C}$ . In the 1.25Cr 1Mo 0.25V steel the resulting structure (bainite) first formed a fine dispersion of  $\text{V}_4\text{C}_3$  particle in the matrix, and then  $\text{M}_3\text{C}$  and  $\text{M}_{23}\text{C}_6$  were formed. The latter are larger and precipitate on the grain boundaries.

Chaudhuri and Ghosh, 2009 suggest that the carbide coarsening is the dominant microscopic mechanism of creep in 2.25 Cr-1Mo steel. The present work shows that the creep behaviour of these steels is very sensitive to the initial microstructure. In this sense, not only a precipitation evolution is involved in this process but also grain changes are observed.

#### 4. Conclusions

From the obtained results we can conclude that:

- The microstructure of the material under stress states and high temperature shows deformed grains with smaller size in comparison with the as received material. It was also observed an increased precipitation of carbides with the consequent decomposition of the colonies of bainite. This effect becomes more noticeable as the test temperature increases.
- In the material that was thermally treated it was observed that for both steels the precipitation of carbides increases with increasing test temperature. In the 2.25Cr 1Mo steels the original structures ferrite-bainite was maintained with a decrease in the content of bainite while in 1.25Cr 1Mo 0.25V steel the bainitic structure remains.
- The activation energy in both steel is greater with increasing applied stress. This parameter is higher in the 1.25Cr 1Mo 0.25V steel, this behaviors indicates less resistance to creep of this steel.
- The values obtained for stress exponent “n” increase in the 1.25 Cr 1 Mo 0.25V steel. This parameter indicates that the dominant process in flow is the movement of dislocations. During their movement, the dislocations increase their piling up when they meet the carbide precipitates in the matrix. Due to the high temperature that accelerates the process of climbing a change of slip plane is possible.

#### References

- Bailey J., Sheikh-Ahmad J., 2001, “Fundamental Aspects of Torsional Loading”, ASM Metals Handbook, Vol. 8,
- Bhadeshia H.K.D.H., 2001, Bainite in steels, transformations, microstructure and properties, 2<sup>nd</sup> Ed. Thomson, R.C.;
- Chaudhuri S, Ghosh R.N., 2009, Creep behavior of 2.25 Cr 1 Mo steel- Effects of thermal ageing and pre strain, *Materials Science and Engineering A*, Vol. 510-511,p 136-141.
- Evans R. and Wilshire B., 1985, Creep of metals and alloys. The Institute of Metals, England.
- Thomson R.C.; Bhadeshia, H.K.D.H., 1992, Carbide precipitation in 12Cr1MoV Power Plant Steel, *Metallurgical Transactions A*, vol. 23A,p 1171-1179.
- Viswanathan R., 1989, Damage Mechanisms and Life Assessment of High Temperature Component. ASM International Metals, Park Ohio, USA